

Pest Management Grants Final Report

DPR Contract No. 97-0229

Use of Lime-Sulfur Solution for the Control of Postharvest Mold of Citrus Fruit.

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ABSTRACT

Citrus fruit often rot after harvest because they are attacked by one of several fungi. To control the rot, the fruit are soaked in one of several salt solutions or treated with synthetic fungicides, usually incorporated into waxes used to make the fruit shine. The salt solutions can pose environmental problems in many locations when they must be disposed of, because the salts accumulate in soil and injure plant and animal life. The safety of synthetic fungicides is a concern, and some believe their use should be avoided or minimized. We tested a sulfur solution used as a soil amendment or added to a sewer system, often added to improve flow rates in soils, and we propose to use old solutions used for fruit treatment could be similarly disposed of. Organic growers have long used lime-sulfur solution when growing crops because of its safety. Our work demonstrated that a lime-sulfur solution can be effectively used on citrus fruit, and this practice has been approved and has entered commercial use.

EXECUTIVE SUMMARY

Postharvest green mold of lemons, caused by *Penicillium digitatum*, was reduced more than 80% by immersion of the fruit for one minute in a solution of 3% lime-sulfur solution in water in laboratory and tests with commercial equipment and was equal to other treatments available for this purpose. It reduced sour rot, caused by *Geotrichum citri-aurantii*, about 50% in laboratory tests. A significant advantage of lime-sulfur solution is that because it is applied to soil as a conditioner, disposal of spent solutions to land or sewers may be approved more easily when compared to other compounds that are not approved for soil applications (such as borax/boric acid, sodium carbonate, or sodium ortho-phenyl phenate). Heat improved the effectiveness of lime-sulfur solution for the control of both green mold and sour rot. Risk of injury to fruit was low. Under commercial conditions, tank lime sulfur solution concentration was easily monitored with a hydrometer or salt refractometer calibrated for lime-sulfur solution. The treatment was equal in effectiveness to many other treatments and fungicides employed for this purpose. High pressure water cleaning of fruit after lime sulfur treatment slightly improved its efficacy; this cleaning reduces the efficacy of soda ash or borax-boric acid tank solutions already in use. Spores of *P. digitatum*, the green mold pathogen, survived more than 6 hours in the 3% (wt/vol) lime-sulfur solution at 21°C (70°F), but were killed within 2 hours when the solution was heated to its recommended use temperature of 40.6°C (105°F). Lime-sulfur solutions did not reduce sporulation of the pathogens on those few fruit that did decay after treatment, a benefit obtained with most fungicides that leave fungicidal residues. Lime-sulfur solution has an odor of hydrogen sulfide that was below safety thresholds but it could constitute a nuisance to workers exposed to it for long periods. Ventilation of lime-sulfur solution is needed in some facilities where staff would be in close proximity to the lime-sulfur tank.

This treatment has been incorporated into existing citrus packing lines, the first was Associated Citrus in Yuma, Arizona, in the fall of 1998, followed by several other facilities in Arizona and California.

Several aspects of this research are in progress because of delays due to the weather, or they are issues that only recently were recognized. These include: 1) A large demonstration experiment, originally scheduled for January 1999, was delayed until March 12-14, 1999, because freezing weather in December, 1998 destroyed fruit intended for the January test; 2) The identity of sulfur residues on fruit after treatment is under examination. In a preliminary test, we found treated fruit have sulfur in a form that can give a positive reaction in the Modified-Monier Williams distillation method for sulfur dioxide, although it is very unlikely sulfur dioxide residues are present. The Modified-Monier Williams procedure is used to quantify sulfur dioxide residues in foods. We speculate elemental sulfur has been converted during this distillation to a volatile that is titrated at the end of procedure; we have ion chromatography tests in progress to identify the form of these residues; and 3) deposits on equipment and within pumps accumulate during lime-sulfur solution use. We plan to evaluate chelates to determine if they can minimize this problem, which we presume is caused by the formation of calcium carbonates from carbon dioxide entrapped from air into the solution.

BODY OF REPORT

INTRODUCTION

Green mold of citrus, caused by *Penicillium digitatum* (Pers.:Fr.) Sacc., is one of the most economically important postharvest diseases of citrus worldwide. In California, losses of about 2% and 5% of orange and lemons in storage, respectively, occur each year. The primary infection courts of *P. digitatum* are wounds on fruit inflicted during harvest and subsequent handling. Eradication of these infections is required to achieve acceptable levels of control. Currently, green mold is controlled in the United States by applications of the fungicides ortho-phenyl phenate, imazalil, and thiabendazole. New methods are needed, because pathogen resistance to these chemicals has developed, and regulatory issues and public concerns about health risks of ingesting fungicide residues threaten the continued use of fungicides in the future.

We evaluated a combination of heat and chemical control, employing compounds that have well-studied environmental and animal toxicological properties and extensive precedents as additives or natural components in foods. By selecting these compounds, we hope to facilitate their approval by minimizing health, environmental, and disposal issues. A cleaning process that meets these criteria is the immersion of fruit in heated solutions of sodium carbonate or bicarbonate, a practice first described about seventy years ago. Although we found it worked well, disposal of the high pH and sodium content solutions after use can prohibit their use in some locations. Therefore, we evaluated many other compounds, and found that lime-sulfur solution, first described in early in the nineteenth century and one of the oldest fungicides, worked well in repeated tests. A yellow-orange solution, 10.6 lbs/gallon and pH 11.5, it is a mixture of $\text{CaS} \cdot \text{S}_x$ (calcium polysulfide and small amount of calcium thiosulfate). It is prepared by combining hydrated lime ($\text{CaO} \cdot \text{H}_2\text{O}$) with elemental sulfur. It releases small amount of hydrogen sulfide, and when diluted below 1.5% (wt/vol) or at lower pH, it oxidizes to sulfate and calcium with elemental sulfur precipitation or “blooms.” It is stable for many months in 29% a.i. calcium polysulfide in “Liquid Lime Sulfur Solution” formulations. Lime-sulfur solution is used to open sewer lines, immobilize metal ions and salts in mine soil remediation, adjust soil pH down, and improve water penetration properties of soil. As a pesticide, first described in 1802 by Forsyth, King’s gardener in England, for control of mildew. The present lime sulfur formula standardized in 1850 by Grison, head gardener at Versailles. “Grison’s Liquid” was in common use by 1900 for apple scab, powdery mildew, San Jose scale, aphids, mites, brown rot of peaches, and other pests and diseases. It is used below 26°C in field applications to minimize phytotoxicity to foliage. Most safety concerns are from hydrogen sulfide evolution. OSHA limits for hydrogen sulfide are 10 ppm workplace (8 hours) and 15 ppm short term (15 minutes). Lime-sulfur solution has acute but no chronic toxicity hazard or carcinogenicity, and its oral LD_{50} (rat) is 820 mg/kg. It is moderately irritating to skin.

In this report, our objective is to present the results that indicate lime-sulfur solution works effectively for citrus fruit postharvest applications, and to evaluate variables associated with its practical use, such as the influence of temperature, contact time, lime-sulfur solution concentration, and injury to fruit.

MATERIALS AND METHODS

Standard methods used to evaluate citrus postharvest fungicides were used (Eckert, J. W., and Brown, G. E. 1986. Evaluation of postharvest treatments for citrus fruits. Pages 92-97 in: Methods for Evaluating Pesticides for Control of Plant Pathogens. K. D. Hickey, ed. American Phytopathological Society, St. Paul, MN.) Lemons and oranges used in all experiments were California - grown and selected by hand from field bins after harvest, before any commercial postharvest treatments were applied. Lemons selected were light green to pale yellow in color and used within one or two days. The day before each experiment, the fruit were washed with water on commercial processing equipment, randomized, and inoculated. Petri dishes of potato dextrose agar were inoculated with *P. digitatum* isolate M6R (from J. W. Eckert, University of California, Riverside) and incubated at 20°C for 1 to 2 weeks. Spores were rubbed from the agar surface with a glass rod after a small volume of sterile 0.05% Triton X-100 was added. The spore suspension was passed through two layers of cheesecloth and diluted with sterile water to density of 0.1 at 420 nm. This density contains approximately 1×10^6 spores per ml and is recommended for evaluation of postharvest treatments to control green mold. Each fruit was wounded and inoculated once by dipping a stainless-steel rod in the spore solution and making a puncture injury 1 mm wide by 2 cm deep on each fruit. The shallow wounds penetrated the albedo tissue but not the juice sacs and simulated natural inoculation. After inoculation, the fruit were incubated for 24 hours at 16°C to 20°C, then treatments were applied. Fruit were inoculated in sour rot tests similarly, with the following changes. Arthrospores of two-week old cultures of *Geotrichum candidum* (isolated from lemon) in 10 ppm cyclohexamide were adjusted to an optical density of 0.2 at 425 nm (about 1×10^8 arthrospores per ml), the fruit were inoculated as previously described by a standard puncture, and twenty-four (± 1) hours later after storage at 16 to 22°C, lime sulfur treatments were applied to four replicates of 25 lemons each.

To determine the toxicity of lime-sulfur solution to *P. digitatum*, spores at a concentration 20,000 spores/ml in water, prepared as previously described, were exposed to lime sulfur solution or water in 50 ml aliquots in a temperature-controlled bath at 21°C or 40.6°C. Periodically, 5 ml aliquots were removed, placed on 3-micron pore-size filters in a filter apparatus, rinsed with three aliquots of 10 ml each of sterile water, and placed on potato dextrose agar. After 18 hours, the germination of the spores was assessed.

In all laboratory tests, fruit were dipped into the treatment solutions contained in stainless-steel, computer-controlled heated tank system with twelve 22 L capacity tanks. Each tank contained a spinning propeller agitator, heating coil, and thermocouple. The temperature, lime-sulfur concentration, and length of lime-sulfur solution contact were varied in tests; these parameters are reported within each figure or table in the results. The lemons were treated in plastic baskets in four or five replicates of 25 fruit each, rinsed with 250 ml water, placed in plastic cavity trays, and stored 1 or 2 weeks at 15 to 20°C before the incidence of green mold infected fruit was counted.

In tests with commercial equipment were conducted at the University of California Lindcove Research and Extension Center (CREC) packline facility. The semi-commercial testing here included larger numbers of fruit per replicate and both oranges and lemons, and included other processes typical of commercial packing operations, such as high-pressure water washing, waxing, and heated-air drying. Hydrogen sulfide was monitored 20 cm above lime sulfur tank and along packline at Lindcove CREC during five hours of operation of the heated 2000 L tank with mixing jets and advancer on. Although the odor of H₂S was present, the CREC staff did not describe it as objectionable. The dose of hydrogen sulfide was not detectable by the dosimeters (Dräger® and Symsidyne®) and therefore was below the 1 ppm sensitivity of the dosimeters.

In tests at Lindcove CREC to evaluate several variables on lime-sulfur solution effectiveness and to compare it to other treatments, lime-sulfur solution (3% wt/vol) was applied to four replicates of 75 to 100 fruit each at two temperatures (ambient or 105°F) for two residence periods (1.5 minutes or 3 minutes) followed by a light water rinse (ca. 10 ml fresh water fruit) or pressure washing. Controls included: 1) untreated but inoculated; 2) immersion for 3 minutes in 3% soda ash in tank alone; and 3) immersion for 3 minutes in 3% soda ash in tank alone; followed by 2000 ppm in finishing wax. The residence time in the pressure washer, which operated at 250 psi, was about 45 seconds. The pressure washer was 61 cm wide, 3 m long, and contained fifteen rows of three 45°C flat-fan nozzles per row. Each nozzle applied 100 ml of water per second. The water in the pressure washer contained 10 µg/ml of sodium hypochlorite. After pressure washing, the fruit were waxed with a finishing wax (Brogdex Britex 505) and dried at 120°F. The test was repeated twice the same day, once with Valencia oranges and once with Eureka lemons. Fruit were randomized, treated, and stored at 10°C (52°F) for 15 days at Lindcove, then the incidence of green mold was determined.

In tests at Lindcove CREC to evaluate several variables on the risk lime-sulfur solution could injure fruit, lime-sulfur solution (3% wt/vol) was applied to three replicates of 75 to 120 fruit each at three temperatures (105°, 120°, or 130° F, or 40.6°, 48.9°, or 54.4° C) for one residence periods (3 minutes) followed by pressure washing at 250 psi. The test was repeated five times the same day with to five early- or mid-season navels (Atwood, Thomsom Improved, Fisher, New Hall, Bonanza) and Lisbon lemons. Fruit were randomized, treated, waxed with a finishing wax (Brogdex Britex 505), dried at 120°F, and stored at 10°C (52°F) for 7 weeks at Lindcove. Then, the fruit in each box were sorted visually into four classes: 1) perfect; 2) slight but not significant rind blemish present; 3) modest rind blemish present; or 4) scald injury present. Fruit within the first two classes are USDA No. 1, those in the last two classes would be choice, standard, or juice-grade fruit.

The lime-sulfur solution was donated by Best Sulfur Products, 5427 East Central Avenue, Fresno, CA 93725. It contained by weight 29% calcium polysulfide. The treatment solutions were prepared by dispensing lime-sulfur solution, usually at 3%, by weight to volume into the stainless tanks. The active concentration of calcium polysulfide in a 3% w/v lime sulfur solution is 0.87%. The effectiveness of lime-sulfur solution was compared to sodium carbonate and borax-boric acid solutions and the fungicide imazalil (Bromazil 50™, Brogdex Co.); treatments whose efficacy for the control of green mold have been well investigated.

RESULTS

The incidence of green mold was equally reduced by the immersion of inoculated lemons in 2, 3, 4, 5, or 6% wt/vol lime-sulfur solution at 105⁰ F for 90 seconds (**Figure 1**). [Lime-sulfur solution rates lower than 2% could not be tested because elemental sulfur precipitated from the solution at 1.5% wt/vol or less.] No injury to the lemons was observed after storage of the lemons after any treatment.

The incidence of green mold was progressively reduced by the immersion of inoculated lemons in 3% wt/vol lime-sulfur solution at 105⁰ F for 15 seconds, 1, 2, or 4 minutes (**Figure 2**). No injury to the lemons was observed after storage of the lemons after any treatment.

The effectiveness of a 3% lime-sulfur solution treatment for the control of citrus green mold was not significantly different from sodium carbonate or borax-boric treatments (**Table 1**). Water alone at 105⁰ F did not reduce green mold significantly. Lime-sulfur treatment reduced green mold incidence by 93%, 88%, and 80%, respectively, in tests one, two, and three. No injury to the lemons was observed after storage of the lemons after any treatment.

The effectiveness of a 3% lime-sulfur solution treatment for the control of sour rot of lemons was significantly different from the inoculated control and the treatments reduced sour rot incidence by an average of about a 50% reduction (**Table 2**). Increasing the lime-sulfur solution concentration or treatment time did not significantly improve control of sour rot. Treatment at 110⁰ F was significantly superior to treatment at 70 or 90⁰ F. No injury to the lemons was observed after storage of the lemons after any treatment.

Lime sulfur significantly reduced the incidence of green mold on both oranges and lemons, and was equal or significantly superior to a soda ash tank treatment or soda ash followed by the fungicide imazalil in wax (**Table 3**). Heating the lime sulfur solution, increasing the contact period of the fruit in the lime sulfur solution, and pressure washing the fruit after lime sulfur treatment significantly improved its effectiveness. No injury to the lemons or oranges was observed.

The percentage of fruit marketable as USDA No. 1 of six citrus fruit cultivars was not influenced by 3% wt/vol lime-sulfur treatment at 40.6⁰ C (105⁰ F), and only two cultivars had a reduction in USDA No.1 rating at 48.9⁰ C (120⁰ F) (**Figure 3**). Even at 54.4⁰ C (130⁰ F), the quality of two cultivars (Fisher and Atwood navel oranges) was not reduced. The seven-week storage period used in this test was long and a normal and high incidence of rind breakdown, particularly among navel oranges, had occurred. Most of the quality defects observed were rind pitting associated with senescent fruit; gray-colored rind injuries, presumably caused by lime-sulfur solution scalding, were observed on a few fruit treated at 54.4⁰ C (130⁰ F).

Spores of *P. digitatum* were not killed by exposure for 6 hours in 3% (wt/vol) lime-sulfur solution or water (**Figure 4**). When the solution or water was heated to 40.6⁰ C, they died after 2 hours in the lime-sulfur solution, and about 3.5 hours in water.

DISCUSSION

Lime-sulfur solutions is very likely to be an effective treatment for the control of postharvest green mold under commercial conditions. Lime sulfur was compatible with commercial processing and provided excellent control of green mold without injury to the fruit. There is little risk of injury to the fruit, because lemons were not injured when exposure times were as long as 4 minutes, as hot as 110⁰ F, or treated in lime-sulfur solution concentrations as high as 6%.

Lime-sulfur solution treatment could be incorporated commercially as shown in **Figure 5**, although many other configurations could be conceived that would also be effective. It is very important that attention be paid to sanitation of the fruit after treatment, because lime-sulfur solution treatment probably does not leave protective residues on the fruit. Therefore, contamination by spores from the air or contaminating packing equipment could inoculate the fruit through wounds made during handling after lime-sulfur solution treatment. Opportunities for re-contamination are minimized if the lime-sulfur treatment is applied at the end of the packing process, after sorting and grading, and just before waxing. This way, exposure of the treated fruit to contamination is minimized.

Some practical questions about lime sulfur solution remain. Preliminary experience in commercial settings indicate the life of the lime-sulfur solution in a packing line is about two weeks, and must be partially recharged daily to keep the concentration at 3% wt/vol. How much of a problem would the 'rotten egg' odor of lime-sulfur solution be in a packing-house? It has not been a serious problem in the well-ventilated facilities that are testing it. Lime-sulfur can be applied before or after pressure washing integrated because vigorous washing did not reduce its effectiveness as it does the effectiveness of borax-boric acid or the carbonates. Other work in our laboratory showed the solution does not kill the pathogen spores immediately, but causes a persistent, non-cidal inhibition of their growth like the fungicides, borax-boric acid, and the carbonates. The spores germinate very slowly after lime sulfur treatment, even when they have been rinsed repeatedly with fresh water, which suggests the lime sulfur leaves a persistent residue on them. They die slowly when the solution is heated. The compatibility of lime-sulfur solution treatment with biological control treatments is not known. These questions will be answered in future tests. Associated Citrus packinghouse in Yuma AZ began the first commercial lime-sulfur treatment in October 1998, shortly after it was approved for use, and more facilities plan are testing the treatment in 1999.

SUMMARY AND CONCLUSIONS

- In collaboration among the USDA-ARS, Sunkist Growers, and the producer and registrant Best Sulfur Products, we showed how lime-sulfur solution could be used to replace less environmentally friendly fungicides for packinghouse use for the control of postharvest rot of fresh citrus fruit.
- Lime-sulfur can control green mold as well as the available fungicide or tank treatments, it can solve disposal problems, and it does not leave persistent residues on the fruit, and it can be used to manage fungicide resistant isolates of *P. digitatum*.

- Heat improved lime-sulfur effectiveness. Unlike soda ash and borax-boric acid solutions, pressure washing of fruit after treatment did not diminish lime-sulfur effectiveness.
- Risk of injury to fruit was low.
- Hydrogen sulfide odor of lime-sulfur was below action levels for safety purposes, but it could be a nuisance for workers if they are adjacent to the solution for long periods.
- Lime-sulfur concentration was safely and easily measured with a salt refractometer or hydrometer.
- Used lime-sulfur solution can be safely disposed of, proposals include its soil application to agricultural soils, or it may be returned to the manufacturer for re-use or for soil remediation purposes.
- Lime-sulfur reduced sour rot, caused by *Geotrichum citri-auranti*, from 64% to 35%. Control of this more minor pathogen was only fair, but there are not fungicides currently registered for its control in the U.S.

LIST OF PUBLICATIONS

Smilanick, J. L., and Sorenson, D. 1998. Use of lime sulfur solution for the control of postharvest decay of citrus fruit. *In press* in Proc. 7th Int. Cong. Plant Pathol., Edinburgh, Scotland.

Smilanick, J. L., 1998. New methods to control postharvest decay of citrus. Progress report, California Citrus Research Board, includes: " Use of lime sulfur solution for the control of postharvest decay of citrus fruit".

Smilanick, J. L., and Sorenson, D. 1999. Use of lime sulfur solution for the control of postharvest decay of citrus fruit. *In press* in: Fruit News, M. L. Arpaia, Editor.

Table 1. Incidence of green one or two weeks after the treatment of lemons inoculated with spores of *Penicillium digitatum*. The temperature of the water, lime-sulfur solution, sodium carbonate, and borax-boric solutions was 105⁰ F. The fruit were immersed for 2 minutes in test #1, and for 1.5 minutes in tests #2 and #3.

Green mold incidence (%) among stored lemons ^y				
Treatment	Test #1 ^z 6.20.97	Test #2 7.17.97	Test #3 98.97	All tests means
Inoculated, otherwise untreated control	99 a	99 a	97 a	99.1 a
Inoculated, 105 ⁰ F water-treated control	91 b	99 a	97 a	96.0 a
Lime-sulfur solution 3% w/v	7 c	12 b	19 b	13.2 b
Sodium carbonate 3% w/v	20 c	14 b	14 b	15.7 b
Borax-boric acid 4%/2% w/v	NA	9 b	13 b	11.1 b

^y Means in columns followed by the same letter are not significantly different (Fisher's Protected LSD; $P = 0.05$).

^zThe lime-sulfur solution contained 2.5% w/v in this test.

Table 2. Incidence of sour rot among lemons inoculated with 10^8 arthrospores per ml with 10 ppm cyclohexamide 24 hours before treatment with lime sulfur in tanks. The fruit were stored at 20⁰ C (68⁰ F) for two weeks after treatment.

Lime sulfur (%)	Temperature (⁰ F)	Contact time (min)	Sour rot (%±SD)
Inoculated, not treated	NA	NA	64 ±07.3
0 (water alone)	110	3	51 ±13.2
2	70	1.5	37± 8.9
3	70	1.5	31± 8.9
4.5	70	1.5	37±16.1
2	90	1.5	52± 8.6
3	90	1.5	45±15.1
4.5	90	1.5	34± 7.7
2	110	1.5	28±17.0
3	110	1.5	39± 8.9
4.5	110	1.5	31± 8.3
2	70	3	45±14.0
3	70	3	45±12.4
4.5	70	3	41±10.5
2	90	3	47±16.5
3	90	3	36± 5.7
4.5	90	3	35±14.4
2	110	3	22±10.1
3	110	3	35± 6.0

Statistical analysis interpretation ($P = 0.05$)

Was control of sour rot significant?	YES, it was reduced about 50%
Did increasing lime sulfur improve sour rot control?	NO
Did increasing the temperature improve sour rot control?	YES (110 better than 70 & 90)
Did increasing the contact time improve sour rot control?	NO

Table 3. Incidence of green mold among lemons and oranges after 15 days storage at 52⁰ F. The fruit were treated with lime sulfur, soda ash, or soda ash followed by 2000 ppm. imazalil in finishing wax. All treatments were applied 24 hours after inoculation with spores of *Penicillium digitatum*. The test and subsequent storage were conducted at Lindcove Citrus Research and Extension Center, Lindcove CA.

Treatment	Temperature (EF)	Incidence (%±SD) of green mold infected fruit			
		Contact Time (min)	Pressure Washer	Lemons	Oranges
Inoculated untreated otherwise	NA	NA	NA	100.0 ±0.0	90.0 ±7.2
3% Lime sulfur	80	1.5	NO	15.7 ±6.9	35.5 ±2.5
3% Lime sulfur	80	3.0	NO	13.6 ±2.3	45.4 ±6.3
3% Lime sulfur	80	1.5	YES	11.1 ±6.2	34.6 ±7.7
3% Lime sulfur	80	3.0	YES	8.0 ±3.8	26.3 ±3.4
3% Lime sulfur	110	1.5	NO	2.7 ±1.1	15.5 ±2.9
3% Lime sulfur	110	3.0	NO	1.7 ±1.3	6.7 ±2.4
3% Lime sulfur	110	1.5	YES	2.3 ±1.3	10.8 ±2.2
3% Lime sulfur	110	3.0	YES	0.7 ±0.8	3.3 ±1.4
3% Soda ash	110	3.0	YES	2.7 ±1.1	10.4 ±6.0
3% Soda ash, then 2000 ppm imazalil	110	3.0	YES	1.7 ±1.3	10.8 ±4.0

Statistical comparisons (threshold of significance = 95% confidence or $P = 0.05$)

Did pressure washing improve green mold control?	YES ($P = 0.0247$)	YES ($P = 0.0001$)
Did heating improve green mold control?	YES ($P = 0.0001$)	YES ($P = 0.0001$)
Was control of green mold after 3 min contact in lime sulfur superior to 1.5 min?	YES ($P = 0.0343$)	YES ($P = 0.0008$)
Was 3% lime sulfur at 110 F for 3 min better than 3% soda ash + imazalil?	Lemons NO, $P = 0.2152$; Oranges YES, $P = 0.0138$; YES, $P = 0.0171$.	

These comparisons by paired t -test.

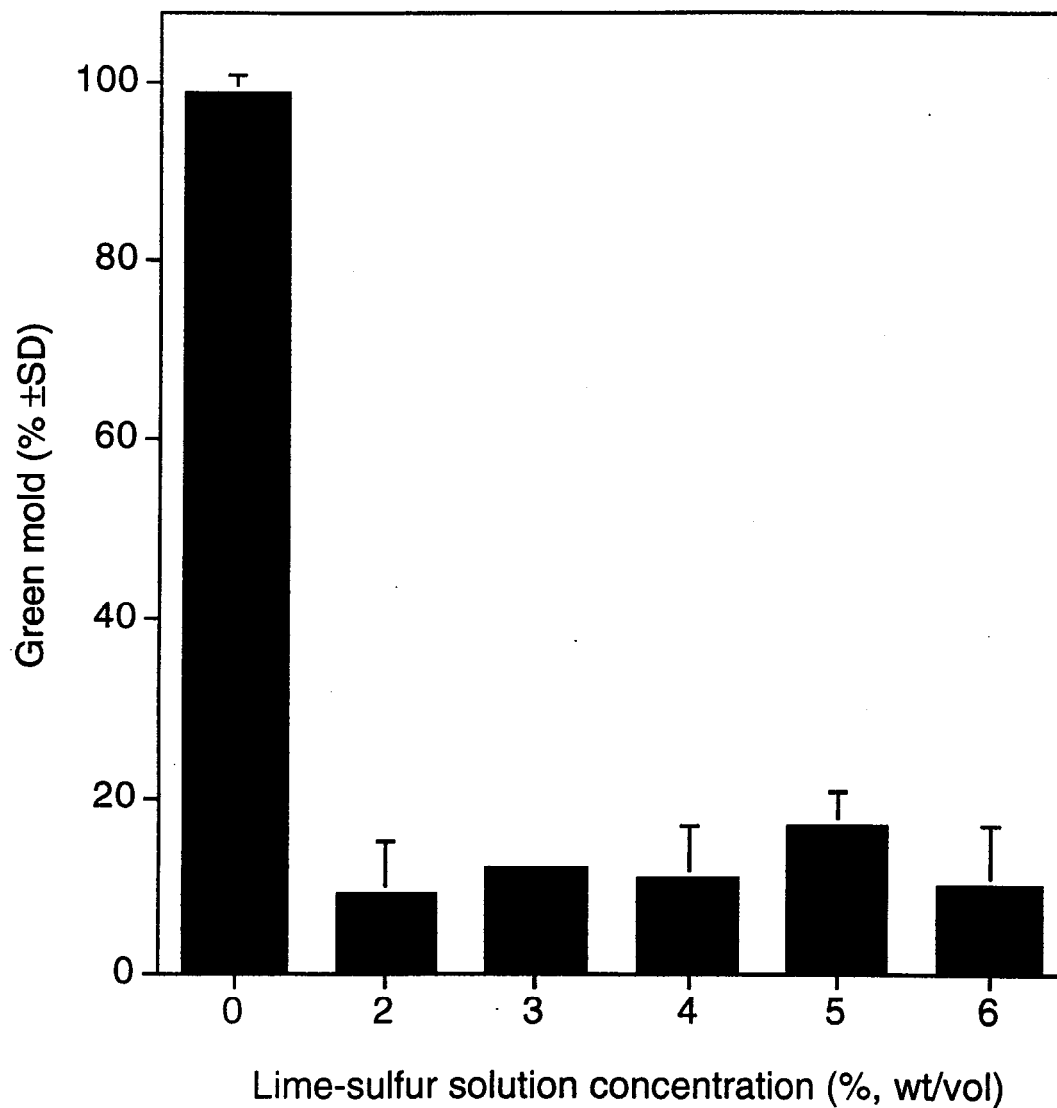


Figure 1. Incidence of green mold on lemons after inoculation with spores of *P. digitatum* followed by treatment in 2 to 6% lime-sulfur solution for 90 seconds and storage for two weeks at 20°C.

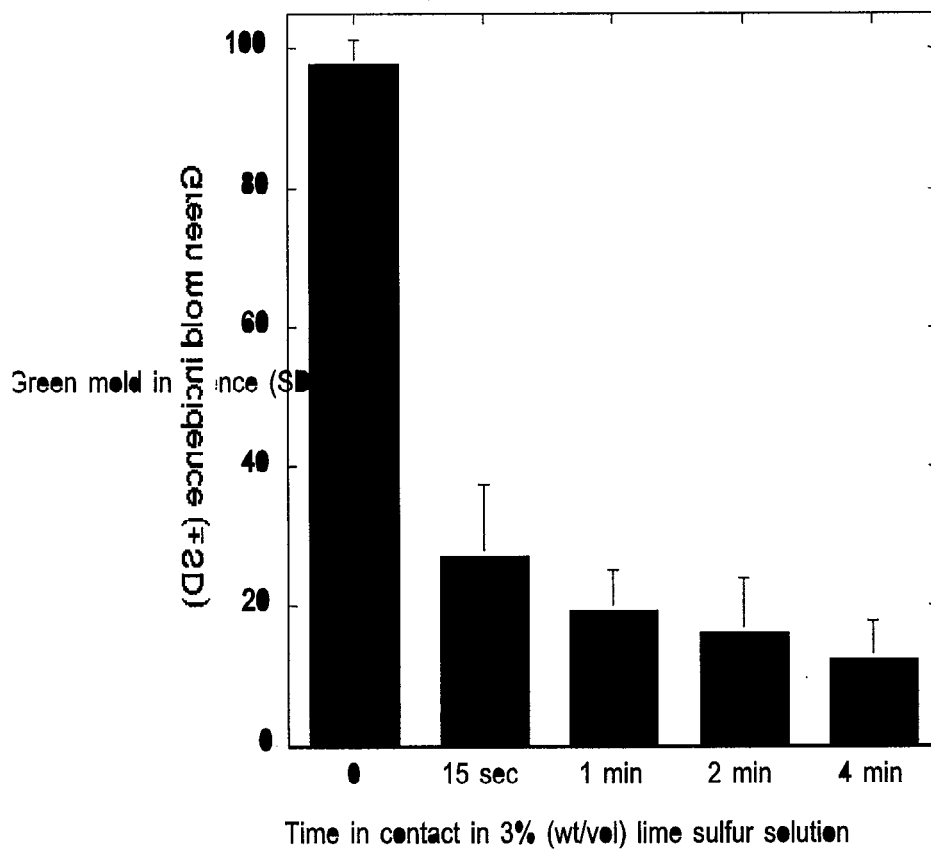


Figure 2. Incidence of green mold on lemons after inoculation with spores of *P. digitatum* followed by treatment in 3% lime-sulfur solution for 15 seconds to four minutes and storage for two weeks at 20⁰ C.

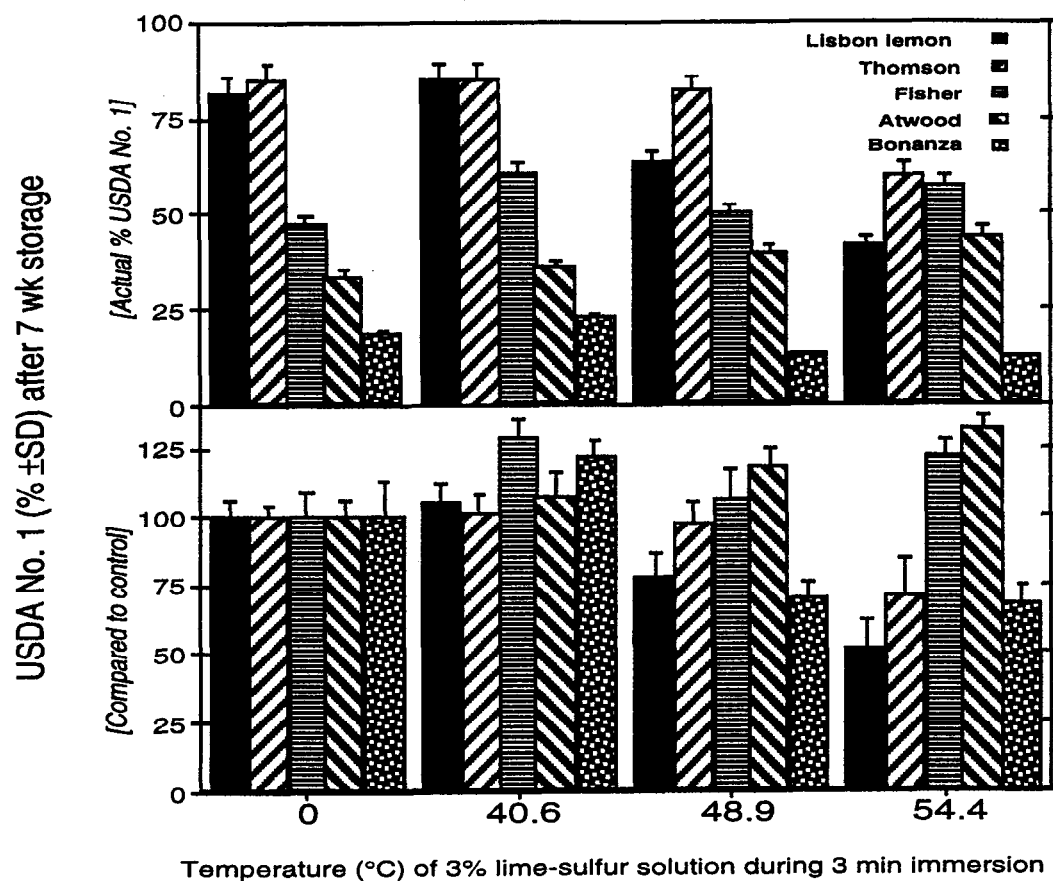


Figure 3. Percentage of fruit marketable as USDA No. 1 of five early- and mid-season navel oranges and Lisbon lemons treated in 3% wt/vol lime-sulfur solution for three minutes followed by storage seven weeks at 10°C (52°F).

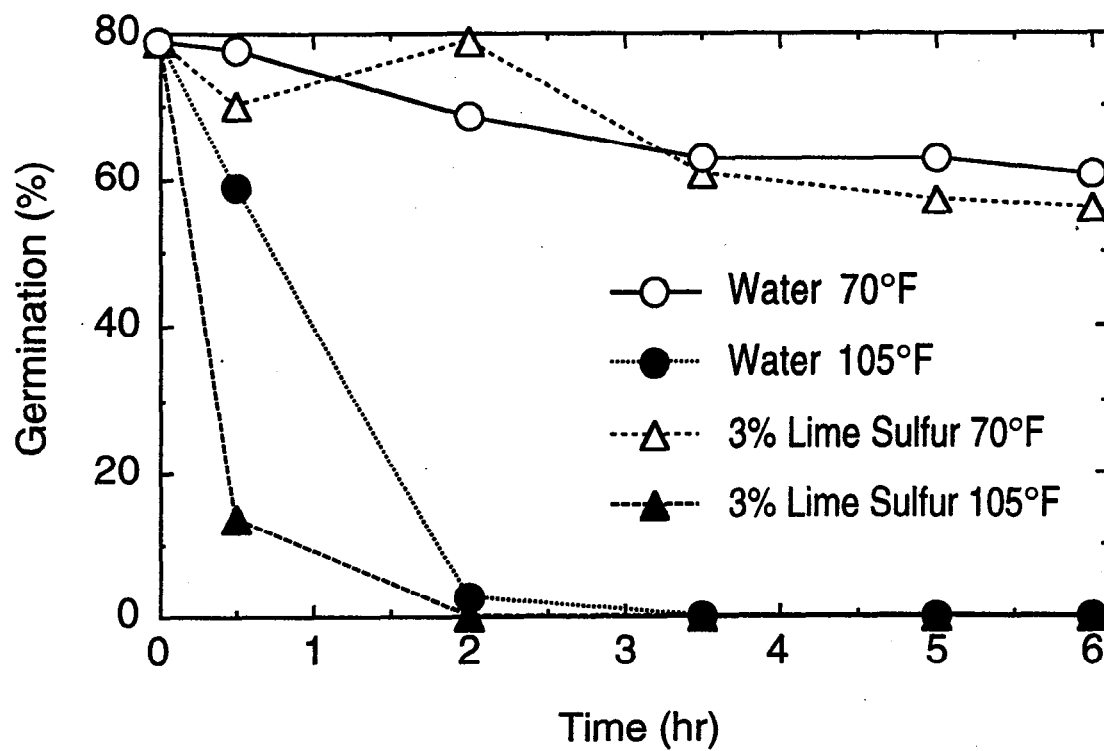


Figure 4. Survival of spores of *P. digitatum* in 3% wt/vol lime-sulfur solution or water at 70°F (21.0°C) or 105°F (40.6°C).

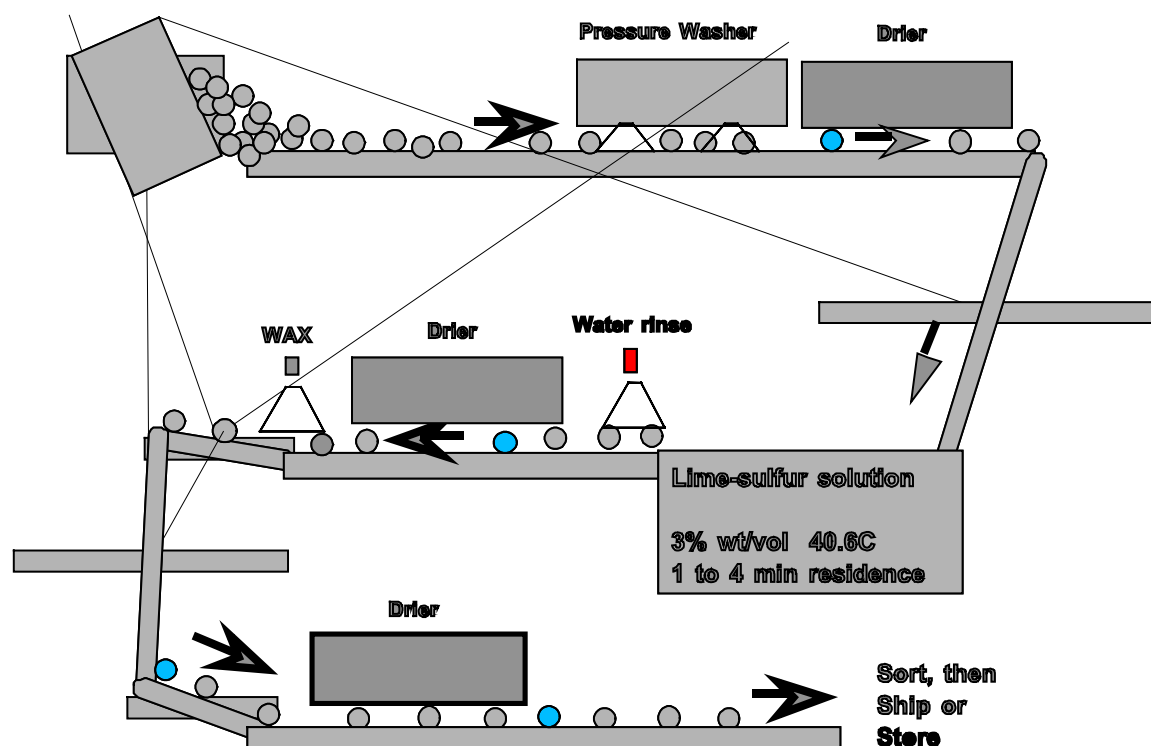


Figure 5. Concept diagram of where a lime-sulfur solution tank is incorporated into a citrus packingline.